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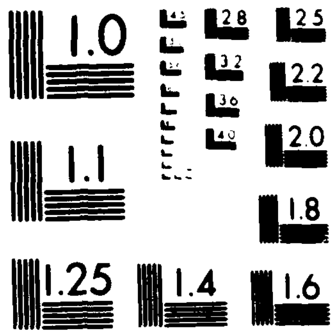

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SUPERSONIC AND SUBSONIC AIRCRAFT NOISE EFFECTS ON ANIMALS: A LITERATURE SURVEY

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NOISE AND SONIC BOOM IMPACT TECHNOLOGY (NSBIT) ADPO
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The purpose of this research is to investigate the literature on the effects of supersonic and subsonic aircraft noise on wildlife. Once the specific literature citings have been identified, we then tried to determine any technological gaps present and make recommendations as to how the US Air Force could fill those gaps. The technological gaps and the recommendations are strictly based on assumed Air Force requirements and not to just fill a void in our current knowledge.

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ABSTRACT

The purpose of this research is to investigate the literature on the effects of supersonic and subsonic aircraft noise on wildlife. Once the specific literature citings were identified, we then tried to determine any technological gaps present and made recommendations as to how the US Air Force could fill those gaps. The technological gaps and the recommendations are strictly based on assumed Air Force requirements and not just to fill a void in our current knowledge.

SUMMARY

We searched the literature concerning the effects of supersonic and subsonic aircraft noise on animals. Our search revealed many review papers of prior research accomplished, but few actual research papers. Out of all the reviews, Dufour's work is the most comprehensive.

Many of the papers are anecdotal in nature and add little to our scientific knowledge- strictly circumstantial evidence.

The literature reveals few effects on animals due to sonic booms. The effects of subsonic noise, however, needs much more investigation. One of the biggest problems with the research in this area is the lack of controls, lack of standardized ways of recording data and evaluating behaviors, and the number of variables involved. Specific recommendations to fill some of the technological gaps include a sonic boom study on a ground-nesting shorebird, effects of subsonic aircraft noise on endangered species, long term physiological effects causing immunosuppression, and noise versus visual aircraft stimuli effects.

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For tens of years environmentalists, scientists, naturalists and other concerned citizens have become increasingly aware of the problems we have created by our noisy technology. Since jet aircraft make loud noises and jet travel has increased tremendously over the years, increased awareness in aircraft flight noise and its effects on the environment have evolved. Authors and researchers have discussed at great length the problems of aircraft noise and its effects on wildlife. Since military aircraft not only create a noisy environment around their bases, but also in military operating areas and ranges, low-level training routes and supersonic corridors, added concern has been placed on the effects of aircraft noise on domestic and wild animals. For these reasons we have reviewed the literature on this topic to determine what has been done that can be directly applied to Air Force concerns and to identify the technological gaps in our present knowledge of the impact of noise on animals.

We must state that the literature review presented here is a summary of most of the pertinent literature on the subject. We have chosen to leave out topics concerned with noise other than aircraft-generated noise or noise in the range usually generated by aircraft. We have also left out some of the laboratory studies on the effects of noise on laboratory animals which do not correlate directly with noise produced from aircraft. In attempting to keep our perspective on this broad topic, we have limited our reviews to papers that pertain to aircraft noise levels between 80 and 125 dB and sonic booms levels below 50 psf except where we thought that the research was significant to our understanding of the subject. Keep in mind that much of the research was done beyond these limits and would not be as useful within these criteria if positive reactions were noted.

The organization of this review on noise-oriented research papers is divided into four parts. Part One (I) is a review of the general effects of noise and methods used by investigators. Part Two (II) contains the summaries of studies applicable to aircraft-generated noise. This section is subdivided into sonic boom and subsonic noise effects on birds, fish, and mammals. Part three (III) addresses how the study conclusions may directly effect military operations. Part Four (IV) is the summary of results, conclusions, and some areas we think requiring further study.

I. Noise Effects and Methods

The noise generated by military aircraft has various effects on domestic and wild animals. Hurtubise, et al (1978a and b) goes so far as to say that noise produces similar effects on wildlife as it does on humans, but the author did not present any research to substantiate this statement. Dufour (1980) has categorized the effects of aircraft noise into four general areas: hearing impairment, communication masking, nonauditory physiological effects, and behavioral modifications. Other authors have divided their reviews in similar ways (Hurtubise, et al 1978a and b). Each article reviewed in this paper investigates the impact of animals in one of these areas except that we have categorized the topics differently. Three general methods to gather these data were used; these consisted of laboratory, domestic and wildlife observations. Many of these papers are simply observations without any scientific basis, but may add credance to other research. Those papers with quantitative results contain a variety of methods using aircraft noise or simulated noise. Besides actual flyovers by many different types of fixed-wing aircraft and helicopters, simulated noise varies even more. Simulated aircraft noise range from shotgun blasts and propane cannon blasts to recorded aircraft noise and sonic boom-producing machines. As often as possible, we included decibel levels and/or sonic boom overpressures for comparisons with other research. The data and conclusions of these papers give a basic foundation for evaluation of the effects on specific organisms, but many questions still remain unanswered. By using the available data and starting research projects in the unstudied areas, the impact of military operations can be assessed.

II. Reviews of Literature

General

Runyan and Kane (1973a and 1973b) provided a reference for investigators in the field of sonic boom research to try to eliminate a duplication of efforts. Unfortunately, we still seem to be duplicating efforts. Others providing reviews include Boutelier (1967), Abraham (1973), Constant, et al (1973), Page and Kaye (1973a and 1973b), Cottereau (1972 and 1978), Fletcher (1979 and 1983), Fletcher and Busnel (1978), Bond (1971), Bell (1972), Department of the Air Force (1972), Slutsky (1975), and Memphis State University (1971). Probably the most extensive review and best critique for research in the 1970s was done for the Noise Abatement and Control Office of the EPA by Dufour (1980).

Dufour compiled an extensive summary of research reviews from 1971-1980 on the effects of noise on wildlife and other animals. The main effects of noise on wildlife that she reported included loss of habitat and territory, loss of food supply, behavioral changes modifying mating, predation, migration, and changes in interspecific relationships including predator/prey and competition for food and shelter. The main reason these effects occur is due to impact of noise on hearing, communication masking, non-auditory physiological effects, and behavioral modifications. She compiled research on organisms into three different areas: laboratory animals, domestic animals, and wildlife.

Dufour concluded from her review of results of laboratory animal studies that there were significant effects on auditory organs during continuous high noise (over 100 dB). These effects were evaluated by Dufour as "much beyond the noise levels organisms around airfields would usually be subjected to and making direct generalizations to non-laboratory conditions would be inappropriate." The benefit of laboratory conditions, though, was the ability to control conditions and precisely measure noise sensitivity and assess hearing damage.

Dufour's research observations on domestic animals led her to think that there was a lack of uniformity and actual measurements of responses of organisms to noise events. Despite this, her general conclusion was that excessive noise caused alarm and flight responses which could have disruptive effects on economically important animals. It appeared that physiological decrease of heart and respiration increase, decrease of milk production, and effects mating and reproductive success caused by excessive environmental noise. Long term effects had not been evaluated, but she suspected that habituation could serve to limit reactions by organisms.

In wild animals, Dufour found few quantitatively measured, long term studies in natural settings. Most observations were behavioral responses, subject to human interpretation and hard to distinguish if other stimuli were present. She also noted that hearing sensitivities of many wild animals have not been measured in the laboratory, so specific impacts are hard to evaluate. Animals reported by Dufour as being studied included mammals, birds, reptiles, amphibians, fish, and insects. These animals seem to have a wide range of hearing tolerances and had a wide variety of reactions to noise stimuli.

The Sonic Boom Panel was formed by the International Civil Aviation Organization (ICAO) in 1969 to determine the effects of Concorde-type sonic booms to humans, structures, and animals. Shortly after that the Sonic Boom Committee, also of the ICAO, met to evaluate research and define gaps in the knowledge of effects of sonic booms to the environment. Both the Committee and the Panel published reports of current research efforts (Sonic Boom Committee 1972 and 1973 and Sonic Boom Panel 1970). These reports are brief and do not contain extensive analysis and evaluation of reviewed research.

Effects of Sonic Booms on Birds

For more than fifty years Sooty Terns and Brown Noddy Terns have been breeding on the Dry Tortugas (Austin, et al 1972). Regularly, 50,000 sooties and 2,500 noddies breed on the island. When researchers returned in 1969 to band young, few Sooty Terns were in the area. One half the normal number of adults were present. Only 242 were banded compared to the normal 20,000-25,000. Most eggs found contained partly grown embryos indicating that something disrupted their nesting cycle. All Noddy Terns hatched as normal. Researchers eliminated weather, physical intrusion, shortage of food, natural predators, and pesticides as possible causes of death or disturbance to the young. Researchers presume strong sonic booms, from Navy low-level overflights, disturbed the sooties causing dissertion of nests by the adults. Since no one actually observed the incident, no one can say for sure what happened. Unfortunately, this paper has been cited many times despite all the assumptions that were made.

Casady and Lehman (1967) found that avian species (turkeys, chickens, and pheasants) reacted much more to sonic booms than other farm animals (cows and horses). They noticed some evidence of fright and pandemonium and displayed reactions of running, flying, crowding and cowering. However, more severe reactions were observed as a result of low-level subsonic overflights. Even still, the average reaction produced by the poultry was between no reaction and a mild reaction. Of the 800 booms the birds were exposed to, only nine crowding reactions and twelve reactions of pandemonium were observed. None of the booms caused any deaths. Since there were insufficient numbers of animals tested and some of the animals may have become habituated to sonic booms prior to the tests, Casady and Lehman's results were inconclusive.

Ruddlesden (1971) reported observing two pairs of lapwings nesting on a grassy area near a runway. He exposed the birds to simulated sonic booms, ranging from 50-860N/m (1-18 psf). Ruddlesden said that "even though intensities, pressures, and noises were raised to abnormally high levels, no evidence was found to indicate that the lapwings were perturbed or adversely affected." Unfortunately, only two nests were exposed and the levels and frequencies of the sonic booms were not documented.

A pheasantry, located 0.75 Km from a sonic boom, was also reported on by Ruddlesden (1971). Pheasants were exposed to 66 booms over 72 days. The booms were grouped so that only 11 days included booms which had from 3-10 bangs on those days. Pheasants were not adversely affected by the simulated sonic booms. Ruddlesden's work lacked controlled experiments and consistency of the booms.

Teer and Truett (1973) studied the effects of sonic booms (2 - 5.5

psf, delivered 1-3 times/day) to nesting Mourning Doves, Mockingbirds, Cardinals, and Lark Sparrows. Of the 301 nests followed to termination on the study areas, the only dissimilarities were attributed to predation rates. There was no indication that sonic booms affected the nesting cycle or production rates of the birds as compared to the controls.

Teer and Truett (1973) also studied the effects of overpressures of 5.5 psf delivered up to three times a day to Bobwhite Quail eggs. Seven thousand and twenty-five eggs were used in the study. Teer concluded that pressures had no effects on the eggs nor the mortality of the hatchlings. Tear and Truett's experiments were very sound and added credance to the idea that sonic booms up to 5.5 psf do not affect quail development.

Ellis (1981) studied the behavioral responses of eight species of raptors during 1,000 jet overflights and more than 100 real and simulated sonic booms. Ellis found that raptor responses to real and simulated sonic booms were often minimal and never productivity-limiting. Small nestlings normally did not respond to noise of jet aircraft. Large nestlings often responded by becoming alert or cowering in the nest. Adult birds did not respond when aircraft were 500 meters away. Occasionally adults would flee the nest when aircraft came closer than 300 meters. However, there was never any site abandonment or destruction of eggs or young. Ellis found the birds to be incredibly tolerant of aircraft noise.

Researchers exposed over 3,415 white Leghorn chicken eggs to over 600 sonic booms during a 21-day incubation period (Heinemann and Le Brocq 1965). Of the exposed eggs a hatch rate of 83.2% was observed compared to a mean hatch rate of 81.3% for the controlled eggs. These results showed that sonic booms did not lower or adversely effect the hatchability of chicken eggs incubated.

Higgins (1974) found that while studying the effects of sonic booms on wildlife the continuous songs of perching birds in the field were completely silenced 4-8 seconds prior to the arrival of the boom. The study disclosed that the response coincided with the arrival of the seismic signal propagated through the ground which preceeded the shock wave by 4-8 seconds. After the boom, the songbirds made "raucous discordant cries" for several seconds before resuming their normal songs. Since the strength of the sonic booms were not certain, these observations only provide more anecdotal information.

Davis (1967) noticed 60-70 ravens gathering together from all directions in Central Wales within five minutes after a sonic boom. No function of this flocking behavior was mentioned and no harm was evident to any of the birds because of the boom. Wilson (1971) observed Shags, Fulmars, and Herring Gulls being disturbed by a sonic boom of a Supersonic Transport (SST). The birds flew around for several minutes. Two days later he witnessed Herring Gulls, Cormorants, and Shags being disturbed by a louder boom. The majority of the gulls seemed disturbed for more than 10 minutes while the other species settled down rather soon after the incident. Some of the birds began returning to the cliffs after about 30 minutes. Both Davis' and Wilson's observations were cursory and should be treated as such.

Schreiber and Schreiber (1980) investigated the responses of Cassin's Auklet, Brandt's Cormorant, and Western Gull to auditory (shotgun and carbide cannon explosions) and visual (humans) stimuli. They determined that visual stimuli cause a much greater disturbance than pure auditory stimuli. The auditory stimuli caused head-jerk movements (a startle response) from nesting gulls and cormorants. Non-nesting birds, being less committed to a site, would often fly off after a disturbance, but would usually resettle immediately afterwards. The Schreibers collapsed 17 auklet burrows to see if sonic booms would create problems if the burrows caved in due to booms. Within 20 hours the burrows were re-excavated. Unfortunately, the Schreibers were not permitted to observe the birds during actual booms. Since the carbide cannon was metered between 134 and 140 dB measured at 60m and 40m respectively, we can reasonably assume that similar responses of birds would be found for actual aircraft overflights if visual stimuli were not present. Since visual stimuli apparently cause greater reactions, further studies would have to be accomplished. Even though carbide cannons and shotguns may produce loud enough noises to elicit a startle response, the Schreibers admit that they would have to make observations of animals during sonic boom events to be conclusive that similar startle reactions would be elicited.

Lynch and Speake (1975) made observations of wild turkeys nesting in Alabama being subjected to real and simulated sonic booms. Each nesting bird was subjected to 7-11 booms over a 10-21 day period. Three of the nests were observed while four real sonic booms occurred in the same day. In all instances, the hens became alerted to the boom, but quickly resumed a relaxed appearance. Twenty-one observations were made of brood groups subjected to simulated sonic booms. In most instances the birds became alerted to the launch of the mortar shell, ran towards a wooded area, and then resumed normal feeding behavior. In one instance the birds jumped in the air before running to the woods. Lynch and Speake concluded that sonic booms did not initiate any abnormal behavior in wild turkeys that would result in decreased productivity. These results were quantitatively of little value, but still significant in the overall idea that sonic booms do not cause problems with avian productivity.

Rylander, et al (1974) found that resting and feeding ducks broke off their activities after being exposed to sonic booms (psf not reported). He also observed Herring Gulls making sudden jerky movements while flying and flocks of passerines always leaving the ground and flying out of sight or circling after being exposed to booms. Rylander commented that solitary birds "normally react less conspicuously than a flock of birds" to booms even though he observed no panic reactions.

General observation of birds in the area while undergoing tests of sonic booms on reindeer revealed to observers that the effects were negligible (Rylander, et al 1974).

Effects of Subsonic Noise on Birds

Jeannoutot and Adams (1961) used 78 broody Broad Breasted Bronze turkeys to test whether high intensity jet noise (110-135 dB) affected nesting. The authors found that the birds treated with the sound had significantly shorter nesting periods than groups treated with progesterone or the control.

Stadelman (1958) exposed chicken eggs to 96dB noise inside incubators. No measurable effect on the hatchability or the quality of the chicks were observed. Stadelman then exposed twelve broody hens to 115 dB noise. Eleven out of the twelve lost their broodiness. Only one hen remained broody and hatched one of the twelve fertile eggs layed. Neither Stadelman nor Jeannoutot and Adams (1961) provide information on the significance of their work or possible long term effects.

Hamm (1967) made observations of chickens over a two year period during Army air reconnaissance maneuvers. The author concluded that single stressors of short duration (less than 1 day) was not damaging to egg production; however, activities over three or more days decreased egg production. These observations were purely anecdotal and based solely on claims.

Great Egret, Snowy Egret, Tricolored Heron, Little Blue Heron, and Cattle Egret colonies were studied with respect to low-level military jet overflights (Black, et al 1984). Behavioral responses and reproductive successes were monitored in flyover areas by F-16 aircraft and a control area. Based on the responses of approximately 220 individual birds during 57 overflights, F-16's at 420 knots (KIAS), 500 feet AGL and up to 100 dBA were not observed to alter the reproductive behavior. This study is indicative of the type of controlled experiments that are possible using animals in their natural habitat. Future studies should be modeled after this work.

Researchers studied the effects of jet overflights on Florida Everglade Kites in Dade County Florida (Snyder, et al 1978). The study area held about 12 active kite nests with 30-40 kites using the area. The range of behaviors studied included mating behavior, feeding behavior, nest-building behavior, incubation behavior, care of young, and general flight behavior. The researchers concluded that there was no clear evidence that the kites were adversely affected by jet overflights. These observations are valuable even though no experiments were done. As with all behavioral studies, they are somewhat subjective.

Snyder, et al (1978) also made observations at the Barranquilla

Airport, Columbia of the same species of kite as well as several incidental bird species in the area. Black-collared Hawks, Yellow-headed Caracaras, Greater Black Hawks, Limpkins, Common Egrets, and Black-crowned Night Herons were observed. Neither the kites nor the other raptorial birds appeared to be adversely affected by the presence of the airpor, although aircraft did seem to frighten Common Egrets and night herons.

While studying behavioral responses of Herring Gulls to jet noise near Kennedy International Airport, Burger (1981) found there was no distinction between gull behavior underneath the flightpath and those of a normal colony for subsonic planes (i.e. aircraft other than SSTs). However, she did note that more gulls flew up from their nests and engaged in more fights during flyovers by SSTs. Burger also found that the mean clutch size for the exposed colony decreased while pairs nesting outside the colony, but still exposed to subsonic jet noise, did not exhibit clutch size decline. Burger attributed lower clutch size, possibly, to the frequent fights as a result of SST disturbances, rather than from noise of other aircraft. Burger used controls well and this study is valuable in the overall understanding of the effects of aircraft overflights on birds.

Kushlan (1979) assessed the disruptive effects of helicopter censuses on wading bird colonies and evaluated the accuracy and economics of helicopter use. During his study Kushlan flew over colonies at 120 and 60 meters with a single engine fixed-winged aircraft and a Bell 47G-2 helicopter. Birds in the colonies included Great Egrets, Snowy Egrets, Louisiana Herons, Double-crested Cormorants, Wood Storks, Brown Pelicans, Great Blue Herons and Laughing Gulls. According to ground observers the majority of birds either looked up or stood up, but did not leave the nest when they saw or heard an aircraft. Qualitative evaluations from observation aircraft of the pelicans, storks, Great Blue Herons, and gulls did not reveal see any disturbances either. Kushlan reported that no predation occurred on those few nests in which the adults did not return for up to five minutes. Since Kushlan was interested in determining the effects of helicopters versus fixed-winged aircraft on bird censusing, the actual noise environment was not described in the report.

A working group of the Acoustic Society of America (1980) reported Common Eiders, Lesser Snow Geese, and Oldsquaws were very sensitive to low flying aircraft and helicopters. The group noted that stronger reactions were elicited in flightless sea ducks during low level flights. Rylander, et al (1974) noted goosanders and eiders reacted with weak, startle responses to subsonic overflights (95-138 dB). Rylander also observed solitary birds (Grey Plovers, oystercatchers, and ruffs) displaying a variety of behaviors during overflights. Variations in descriptions such as these make us keenly aware of the little value this information is for determining effects of noise on wildlife.

The effects of helicopters and fixed-winged aircraft on seabirds was also looked at by Dunnet (1977). Dunnet made observations of a mixed colony of Fulmars, Shags, Herring Gulls, Razorbills, Kittiwakes, Guillemots, and Puffins breeding on the cliffs of Scotland. He concluded that neither helicopter nor fixed-wing aircraft at a height of 100m above the cliffs caused any detectable effect on the nesting birds.

Effects of Sonic Booms on Fish

Guppies were observed while a .22 caliber bullet was fired above their aquarium (Wilkins 1972). The bullet produced a shock wave 275 times greater than the normal 1-3 psf sonic booms created by SSTs. Wilkins noted that fish near the surface of the water reacted more than those near the bottom (15 cm deep); however, none of the reactions were violent or harmed the fish. Wilkins noted differences in the reactions of the fish at different depths, even though it was only 15cm, since the penetration depth of the N-waveform is about the same as the N-waveform length on the water's surface (Cook 1969). Since the N-waveform is related to the length of the bullet, speed at which it is traveling, and length above the water (Zepler and Harel 1965), the penetration depth may not be very significant in this case. Therefore, this study is probably not very significant for the purposes of studying aircraft sonic boom effects.

Rucker (1973) studied the effects of sonic booms on both developing fish eggs and fry. In his studies Rucker exposed eggs and fry of Cutthroat, Steelhead, and Rainbow Trout and Chinook Salmon to sonic boom overpressures ranging from 0.55 - 2.7 psf. His study demonstrated that neither fish eggs nor fry were affected by sonic booms. In fact, Rucker suggested that the pressure created by a pebble, stone or boulder dropped into a pool could be compared to the disturbance of a sonic boom.

Effects of Sonic Booms on Mammals

Joint Task Force II, a unit formed by the Department of Defense Joint Chiefs of Staff to investigate special problems of importance to the military, conducted low-level supersonic flights with F-4C aircraft to determine the effects on structures, humans, and livestock (Nixon, et al 1968). Since no cattle were directly underneath the flight track, overpressures experienced by the cattle was estimated to be 50-118 psf. Responses of the cattle were either unrecognizable or an apparent alerting response and trotting a short distance. Ranchers in the area of the tests reported no observable responses to the sonic booms by their livestock. Pilot reports revealed they observed cattle and horses running upon approach of their aircraft. The authors concluded that the reaction was due to visual cues rather than auditory ones.

Plotkin, et al (1972), unsubstantiated by any studies, concluded that overpressures under 20 psf would only cause startle reactions in wild animals. Since this statement is the opinion of these researchers, care must be taken when using this type of information. Even though this may be an overstatement, we assume 2-5 psf would probably not have short term effects.

Casady and Lehman (1967) investigated the effects of sonic booms on farm animals near Edwards AFB, CA. One race horse breeding farm (100 horses), two beef feeder lots (10,000 cattle), one sheep ranch (150 sheep), one commercial dairy (320 cattle), two turkey ranches (125,000 turkeys), two chicken ranches (35,000 broilers), and one pheasant farm (50,000 pheasants) were used in the study. The animals experienced between 85 and 210 booms depending on where the ranches were located from the proximity of the base. Casady and Lehman concluded that the booms had very little effect on the mammals studied. They also noted that the reactions were more pronounced to noise from low-flying, subsonic aircraft than to booms. No significant changes were evident concerning productivity even though the data was insufficient to be statistically conclusive. Casady and Lehman noted that since Edwards AFB performs many supersonic tests, the observed animals had been exposed to booms for years. This may indicate that the animals had become habituated to booms.

Reactions of cattle and sheep exposed to sonic booms and subsonic aircraft noise were observed by Rylander, et al (1974) in Sweden. Rylander made his observations while 20 cattle (dairy cattle, heifers, and steers) and 18 sheep were exposed to 5-12 sonic booms (47 total) ranging from 0.8 to 5.2 psf. Rylander found that even though reactions to booms were few in cattle, "the animal's responses tended to increase with increasing boom levels. Aggressive reactions were observed twice immediately after a boom in which one cow butted another. Ninety-five percent of the standing sheep and 79.4% of lying sheep reacted to the sonic booms by running or rising, respectively. Rylander suggested a possible adaptation of the sheep after two days of testing. Even though reactions in both types of animals were small, Rylander said that "sheep seem... more prone to react to the exposures and display stronger reactions than cattle." As with most of the studies cited in this report, Rylander's (1974) is another one without any statistical analyses. Therefore, this study can only be used as general evidence for the effects of sonic booms on animals.

The Sonic Boom Committee (1973) reported on the effects of Concorde-type sonic booms. Forty pregnant cows were exposed to 20 simulated sonic booms during the first month of pregnancy. No unusual behaviors were observed and an expected average number of calves were born (28). The Committee concluded that Concorde-type sonic booms do not appear to have any effect on gestating cows.

To determine possible harmful effects of aircraft noise on swine, pigs were exposed to short duration (0.36 - 3.6 min) reproduced aircraft noise ranging from 100 - 135dB (Bond, et al 1963). Measurements of heart rate before, during, and after noise exposure were used to determine the effects of the stresses. The investigators found that, in general, the mean heart rate increased 7-12 beats per minute, but that the animals quickly resumed their normal heart rate after exposure. No evidence was found that the rate of growth, feed intake, or reproduction was influenced by reproduced aircraft noise. The researchers also found that there was no detectable injury to the ear, adrenal gland, or thyroid gland of the test animals. Bond used 5-10 animals for controls and 12-15 animals for the tests which was probably sufficient for statistical significance, although no statistics were presented in the data.

Rylander, et al (1974) performed experiments on reindeer to test the effects of sonic booms. Twenty-four reindeer were placed in a corral to observe any reactions. Even though the reactions of the animals increased as the intensity of the boom increased, no panic movements were observed. Espmark (1971) had similar results. Hubbard (1968) reported deer at Eglin Air Force Base, Florida did not show any apparent response to very high intensity booms, yet no levels of intensities were noted. On the other hand, Thomson (1972) reports reindeer being highly disturbed during aircraft overflights. He claimed that energy expenditure from panic reactions could be critical to the life of the animal during winter or when calving. Thomson did not report any data on the specifics of the sonic booms. These opposing observations continue to remind us of the lack of reliable information we really have.

Boutelier (1970) studied the effects of sonic booms on the behavior of army dogs during intense training. Eleven dogs were used in the study where Boutelier used heart rate and behavioral changes as an indication of effects. He found that dog heart rates increased only slightly, but during intense exercises the dogs were unable to focus their attention. No relationship was found between the strength of the booms and behavior.

During the 1960's, claims totalling thousands of dollars were filed against the U. S. Air Force for alleged damage to mink caused by sonic booms. This was supported by the well documented idea that mink can be easily disturbed, especially during the reproductive cycle (eg. Pernu 1968). Because of these claims, a study was performed on Mitkof Island, AK to determine the effects of real and simulated sonic booms on late pregnancy, parturition, early kit mortality and growth of the young (Travis et al 1972). Treated mink experienced three sonic booms, either real or simulated, ranging from 1.6-6.6 psf. The investigators found that there were no significant differences between treated and control groups with respect to any of the physiological aspects tested.

Pernu (1968) disclaimed the mink tests on Mitkof Island. He admitted that most mink ranchers would claim that mink can habituate to noise, including aircraft sonic booms. He claims that government tests failed to mention that the mink tested had been previously exposed to sonic booms. Pernu summarized by saying that the "government tests appear to indicate that mink carefully conditioned to controlled booms can whelp successfully." He continues by saying that "real booms coinciding with the start of whelping can cause serious losses." This evidence has forced court decisions to discount Travis' mink experiments since they could not prove that the test animals were not previously exposed to sonic booms.

Reinis (1978) exposed chinchillas to simulated sonic booms and then checked for the presence of blood clots in the scala vestibuli, scala tympani, and the cochlea of the inner ear. Sonic booms ranged from 2.2 to 5.5 psf and the animals were exposed to either one or ten booms (at 45 sec intervals). Since only three animals were used in each study group, no significance could be found in animals exposed to only one boom of 2.2 psf. However, when the animals were exposed to ten, 2.2 psf booms or one superboom of 5.5 psf, bleeding was found in the inner ears ($p < 0.05$). Reinis indicated that inner ear bleeding may eventually cause permanent damage and impair hearing. He presumed that if permanent damage did occur, it would probably affect hearing at higher frequencies. Since these data show significant effects at the higher frequency, long term studies should be accomplished to see if permanent damage would occur.

Majeau-Chargois (1969) exposed 24 guinea-pigs to 1,000 simulated sonic booms of 130 dB produced once per second. After exposures she dissected the cochlea to determine if there was any tissue damage. Hair cell damage was found only in the apical portion of the cochlea. All other portions of the cochlea were normal. Since low frequency noise stimulates the apical end of the cochlea, hearing loss may occur over time. The author admits that further research must be done to see if more realistic levels of sonic booms would produce similar effects.

Glass (1981) reports that small animals like mice tend to suffer physical damage of the inner ear in the form of bleeding when exposed to sonic booms. He indicated blood would either be absorbed in time or it may destroy cochlear hair cells. More research should be accomplished to determine which effect will occur.

Balabanov, et al (1980) found that guinea-pigs became restless as the frequency of a noise stressor increased to the point that the animals reached a state of extreme excitation at 15 Hz. However, these effects of infrasound cannot be correlated to the effects of low frequency aircraft noise.

Bowles and Stewart (1980) made observations of California Sea Lions, Northern Fur Seals, Northern Elephant Seals, Harbor Seals, and birds during aircraft sonic booms (pressure levels below 90 dB) and overflights. Even though they observed seals abandoning the beaches, panic reactions and temporary mother-pup separations, Bowles and Stewart stated that they did not expect the levels of disturbance observed to be significantly harmful to the populations. But they also concluded that the noise threshold level for Sea Lions was 80-81 dB and anything higher would produce panic reactions. Steinhart (1978) claims that low-flying planes (of unknown altitudes) have generated complaints concerning the disturbances of Elephant Seals- specifically that panicked adults crush their helpless pups. Steinhart also pointed out other incidents that supposedly disturbed wildlife, especially in our national parks and scenic areas, but are unsubstantiated by actual evidence.

The Australian Advisory Committee on the Environment considers that there is no well-documented evidence of adverse effects of sonic booms on animals (Goldberg 1975). He did note that the case of nesting birds may warrant further investigation.

Effects of Subsonic Noise on Mammals

The National Research Council (1982) provided a limited review of the effects of high-level noise on animals. They concluded that there is no conclusive evidence of detrimental effects of high intensity external sound to higher mammals. Bond (1970) provided a good critical review of some of the studies of the effects of noise on farm-raised animals, including dairy cattle, milk, sheep, pigs, and horses. He concluded there was no evidence that indicated any harmful effects of aircraft noise on the animals.

Borg (1979) determined that irrelevant, meaningless, but "realistic" industrial-type sound does not interfere with the health of rats. He also found that hearing loss for rats exposed to 85 dB noise was about 10-15 dB. At 105 dB hearing loss was disproportionately greater. This may indicate that the noise threshold for rats is approximately 80-85 dB.

Parker and Bayley (1960) tried to survey eight Air Force bases that had dairy herds located within three miles of their runways to see if there were any measurable effects from aircraft noise. Among the eight bases, only Lockbourne AFB was able to provide enough data to be considered complete. The survey obtained data on the daily milk deliveries from 182 herds located within the three mile airdrome perimeter. Data from Lockbourne only and from all eight bases collectively did not indicate any evidence that jet overflights had an effect on the milk production of the herds.

Five pregnant cows were exposed to 59 aircraft overflights from six different types of aircraft (Heuwieser 1982). Heuwiesser concluded that effects varied with the aircraft type. Three of the five cows aborted their fetuses and changes in reproductive hormones were observed in other cases. These data indicate that more experiments are needed to determine the relationship of aircraft noise and abortion rates. Heuwieser's finding that effects varied with aircraft type agrees with Rylander, et al (1974) who found that responses of cattle varied more to subsonic noise levels as the levels of noise increased than compared to the response variation induced by sonic booms.

In his preliminary work, Klein (1973) stated that caribou reacted strongly to low-flying Cessna and Piper aircraft. Klein found a greater frequency of strong reactions in summer than in spring. This suggests that disturbances during migration from the wintering grounds were less than when movements were not as strongly motivated. Klein also found stronger reactions occurred in larger groups than in individuals. While making observations in Alaska, Klein noted that Grissly Bears reacted very strongly to aircraft noise, while moose and wolves reacted much less than Caribou to aircraft. Klein's data was from an initial report of a continued study; thus, the numbers within the sample size were small (we did not find a final report). The study does indicate though, that disturbances to animals in flat terrain by aircraft flying 200 feet AGL or lower (ranging between 81-103 dB) was greater than aircraft flying above 200 feet AGL. No panic reactions of Caribou occurred from disturbances of aircraft flying above 500 feet.

Over 700 groups of caribou in Alaska were also studied by Calef, et al (1976). They concluded that panic reactions and strong escape reactions will occur when aircraft approach caribou below 200 feet AGL. When flying above 500 feet AGL in the fall and spring and 1,000 feet AGL at all other times, the observers noted that caribou did not respond in ways that would cause immediate injury. Calef did not make any distinctions between reactions from fixed-winged aircraft and helicopters as did Klein (1973). McCourt and Horstman (1974) found strong reactions of barren-ground caribou to aircraft flying below 300 feet slant range, while only 1-14% of the caribou reacted strongly at altitudes of 300-600 feet. He also noted that caribou reacted more violently to helicopters than to fixed-wing aircraft.

Ames and Arehart (1969) studied the effects of 75 and 100 dB noise on 20 early weaned lambs. Their study showed an increase in heart rate during initial exposure to 100 dB noise and a sharp cessation when stopped.

They did not observe sustained trends in respiration rate. Adrenal and pituatary gland weights declined in weight by over 20%. These data indicate that noise can affect physiologic functions and should be investigated further.

III. Air Force Impact

One way to determine the effects of military aircraft noise on animals is to examine the claims made against the Air Force due to noise. However, if the data is not complete, then the comments made based on them may be inaccurate. Table 1 is a list of claims against the Air Force supposedly caused by low flying aircraft. Table 2 shows a breakdown of the species of animals involved in these claims. Earlier claim totals can be found in Bell (1972). Table 3 shows only 22% of the face value of those claims were paid. This reduction in the amount paid for animal damage claims was due to the lack of evidence provided by the individuals claiming the damage. Milligan, et al (1983) provided detailed descriptions of many of those investigations. His report shows that many claims are unfounded and the inclination of many people is to blame the military for incidents that may have occurred due to circumstances other than what was claimed.

US military bases are located throughout the continental United States in a variety of environments. Almost all biomes are effected by aircraft operations in one way or another. The first area to be considered for Air Force impact is around bases, where subsonic noise is generated from aircraft arrivals and departures usually within a five mile radius of

TABLE 1: ANIMAL CLAIM STATISTICS*

FISCAL YEAR	# OF CLAIMS	# OF CLAIMS SETTELED	AMOUNT CLAIMED	AMOUNT PAID	AMOUNT IN LITIGATION
1968	1	1	$ 12,179.08	$4,692.00	0
1970	1	1	1,154.00	894.00	0
1971	10	10	72,551.13	5,492.58	0
1972	48	48	54,106.77	14,169.53	0
1973	44	44	66,041.11	11,571.50	0
1974	27	27	16,459.67	5,624.30	0
1975	38	38	79,484.72	32,520.82	0
1976	96	96	705,585.85	56,801.83	0
1977	31	31	136,501.38	19,973.17	0
1978	53	53	412,880.45	62,253.98	0
1979	77	72	851,203.45	76,669.01	314,971.65
1980	48	44	477,052.66	307,218.31	13,424.62
1981	65	54	432,250.68	38,046.02	338,467.77
1982	87	60	529,550.43	55,412.56	41,263.27
1983	2	1	12,540.00	40.00	12,500.00

*Data obtained from USAFOEHL Animal Claims Data Repository (1985).

TABLE 2*

CATEGORY	# OF CLAIMS	%OF TOTAL CLAIMS	VALUE CLAIMED	%TOTAL VALUE OF CLAIMS	VALUE PAID	%OF TOTAL VALUE OF CLAIMS SETTLED (PAID)
Animals - cattle	196	31	$607,279.89	16	$208,803.69	30
Animals -general	142	23	509,476.20	13	71,823.06	10
Animals - horses	111	18	587,160.51	15	70,308.49	10
Animals - dogs	53	8	39,816.41	1	7,747.38	1
Animals - chickens	42	7	851,074.79	22	26,502.86	4
Animals - turkeys	15	2	293,725.56	8	275,075.83	40
Animals - hogs	15	2	107,877.12	3	6,392.59	1
Animals - chickens and egg production	11	2	328,175.20	9	3,190.81	1
House, animals, and outbuildings	11	2	118,745.42	3	13,558.05	2
Animals - mink	6	1	394,958.79	10	8,442.00	1
Animals - egg production only	6	1	7,921.01	1	1,166.03	1
House - animals	5	1	10,285.45	1	2,686.52	1
House - animals and outbuildings	5	1	2,933.10	1	1,651.13	1
Animals - cat	5	1	525.94	1	254.94	1
Animals - rabbits	4	1	421.36	1	76.23	1
Animals - pheasants	1	1	164.63	1	0	0

*Data obtained from USAFOEHL Animal Claims Data Repository (1985).

TABLE 3
DATA REPOSITORY ANIMAL CLAIMS AS OF 2 MARCH 1968 TO 30 NOVEMBER 1982*

Total Number of Claims - 628

Number of Claims Settled (paid) - 580 or 92%

Number of Claims in Litigation - 48 or 8%

Total Value of Claims - $3,859,541.38

Face Value of Claims Settled - $3,138,914.07

Actual Amount Paid - $691,379.61

% of Face Value Paid - 22

Value of Claims in Litigation - $720,627.31

*Data obtained from USAFOEHL Animal Claims Data Repository.

the runway. This noise may be almost continuous in nature, ranging up to 120-125 dB off the departure end of the runway. The organisms affected in these areas range from domestic, commercially-grown animals to wildlife living in undeveloped areas near the base. The possible effects on these organisms, keeping the conclusions from the previously reviewed reasearch papers in mind, may vary greatly. If the organisms are highly sensitive, do not habituate, and develop chronic physiological stress problems, then these environments could be detrimental to the organisms. The research reviewed indicates though, this extreme situation doesn't usually exist and only a few cases (Jeannoutot and Adams 1961· excessive broodiness; Hamm 1967: possible production losses; Burger 1981: damage to eggs in nest) does noise have any slight detrimental effect.

The second kind of area military aircraft noise impacts is the supersonic military operating areas and the low-level routes. The sonic booms generated in these areas are usually below 5 psf and low-level flight noise is usually in the high decibels (125 dB) of the subsonic range. Associated with low-level routes is also the movement of aircraft and their shadows causing some reactions. These flight paths tend to be in rural areas, and may cover many miles of prime wildlife habitats. They are not used continuously, so habituation may not occur, but noise events are short duration and normally do not cause extended disturbances. The animals exposed in these areas may include some domestic animals and many types of wildlife including some endangered species. The noise effects on these organisms may include flight and panic reactions (Davis 1967; Casady and Lehman 1967) and desertion, egg mortality, or predation (Austin 1972; Teer and Truett 1973). Since these studies represent only a few specific species and circumstances and most are anecdotal at best, extrapolating effects of aircraft noise on other birds is not reasonable. In fact, all the other studies indicated no detrimental effects to sonic boom noise. Unfortunately, all these studies and observations were not well done or just anecdotal observations and are not supported by reproducible research.

IV. Summary and Conclusions

We have provided a brief summary of the literature cited in Tables 4 through 7. Tables 4 and 5 are a summary of the effects of noise on birds and Tables 6 and 7 include mammals. As you will notice from the tables, we have distinguished between wild versus domestic animals, type of sound used, effects, and whether the study was done in the field or in the laboratory. Also note that the authors are listed according to the primary author in addition to a shortened title to conserve space on the tables.

Habituation

One question that has not been addressed yet is "What is the long term effect of aircraft noise on wildlife?" In other words, "Do animals habituate to noise?" Busnel (1978) contrasts the assortment of wildlife found in and around airport environments and reactions of some wildlife like caribou, sheep, and snow geese to aircraft. Busnel suggests that this divergence of behavior may be do to "a learning process in the case of certain animal populations." In fact, Kull (1984) observed sheep grazing

INVESTIGATOR Study	Date	TYPE BIRD Domestic	Wild	TYPE SOUND Sonic (s)/ Subsonic (ss)	EFFECTS Negative	Neutral/Other	METHOD Field	Lab	IMPLICATIONS
Heinemann Hatchability of Eggs	1965	Eggs (600) Leghorn Chickens		(S) 3-12 psf for 21 days		Decrease number hatch	Generated by F-4C	Eggs in incubator	Direct
Davis Raven Behavior	1967		Ravens (70)	(S) unknown	Flight and dispersal		Obs in wild		None, no data
Casady Domestic Birds	1967	Turkey Chicken Pheasant		(S) 800 artificial booms	Fright and scramble	No long term effects		Artificial noise in incubators	None, low sample size
Ruddlesden Effect of Sonic Booms on Laying Birds	1971	Pheasants	Lapwings (2 pr)	(S) 1-18 psf, 1-10 days, artif 1-18 psf, 66-72 days		No effect on laying, incubation, hatching, & chick rearing	Descriptive, no ctrl group		None, lacked control groups
Wilson Sonic booms & Seabird colony	1971		Shags, Fulmars, Herring Gulls	(S) SST generated, 2 booms		Disturbance & flight response up to 30 mins	Field observations		None, cursory obs
Austin Sooty Terns on Dry Tortugas	1972		Sooty Terns 50,000 prs	(S) possible	Desertion of nests		Assumptions from obs		None, no direct observations
Teer Effects of Sonic Booms on Birds	1973		Mourning Doves (100), Mocking-Birds (25), Cardinals (15), Lark Sparrows (12), Quail eggs (7,000)	(S)2-5.5 psf, 1-3 days	Possible predation	No sig diff with samples & ctrl	Tabulation of hatch rate & fledgling survival compared to control groups	No effect on mortality & survival of hatchlings	Direct
Higgins Response of Songbirds to Seismic Booms	1974		Songbirds (?)	(S) 1.18 psf		Birds stopped singing before booms & slightly disturbed after	Field observations		None, no quantitative data
Rylander Nesting & Feeding Duck Response	1974		Ducks, Gulls, Passerines, & solitary birds	(S) ?	Broke off nesting, sudden flights	Some solitary birds had no effects	Field observations		None, no quantitative data
Lynch Effect of SB on Nesting Turkey	1975		Nesting Turkey hens (3)	(S) 1-2 psf aircraft generated 5-7 artificial booms, 21 days		No significant effects	Field observations		None, small sample size
Schreiber Auditory & Visual Responses	1980		Auklets, Brandt Cormorant, Gull	(S) artificial- shotgun & carbide cannon, visual stimuli		Flight response with visual stimuli	Field observations		Possibly some- no arcft stimuli
Ellis Responses of Raptorial Birds	1981		Falcons sps. Hawk sps.	(S) 1-5 psf, 100 booms, 50 day acrft generated & artificial		No effect	Field observations		Direct, good quantitative data

Table 4: Summary of the effects of sonic booms to birds

INVESTIGATOR Study	Date	TYPE BIRD Domestic	TYPE BIRD Wild	TYPE SOUND Sonic (s)/ Subsonic (ss)	EFFECTS Negative	EFFECTS Neutral/Other	METHOD Field	METHOD Lab	IMPLICATIONS
Stadelman Sound Effects on Hatchability of Eggs	1958	Chicken eggs Broody hens		(ss) artificial 120dB, various exposure periods (ss) artificial 96dB	 Loss of	No effect		Eggs in incubators Noise in pens	Direct None, low numbers
Jeannoutot Sound and Broodiness in Turkey	1961	Turkey (78)		(ss) artificial 10-135 dB for 40 days	Shorter nesting periods		control groups	Hens in pens w/	Possible, but no conclusions or application
Hamm Sound Effect on Hatchability of Eggs	1967	Commercial Poultry		(ss) a/c noise near flight path (2 wks-2 mons) over 2 yr	Decrease laying rate			Study production rates	None, based on claims
Dunnet Effects of Low-flying A/C on Seabird Colony	1977		Fulmars, shags, Gulls, seabirds	(ss) rotor & fixed wing, 2 day		No effects	Field observations nesting under flight paths		Direct, good baseline data
Snyder Impact of Airports on Birds	1978		Raptors, Egrets Limpkins, night herons	(ss) a/c (727) noise, 83-89dB 5 days		No effetcs on raptors, egrets	Field observations		Direct, good baseline data
Kushlan Helicopter Effects on Wading Birds	1979		Wading birds	(ss) Helicopter noise, no data		Birds alerted, but didn't leave nests	Field observations		None, no data
Acoustic Soc. of America	1980		Common Eiders	(ss) Helicopters & Fixed wing a/c	"Very sensitive"		Field observations from low level flts		None, no quantitative data
Burger Behav Responses of Gulls to a/c	1981		Herring Gulls	(ss) 75-96dB a/c noise (B707, 727, 747 and SST a/c)	SST caused panic flt, broken eggs & predation	Normal a/c did not cause abnrml effects	20 obs (1-2hr ea) w/ clutch size cnts		Direct, very good data
Black Low-level Effects on Wading Birds	1984		Wading birds	(ss) 55-100dBH, F-16, 2 breeding seasons studied		No effects	A/C flyovers w/ obs and control area		Direct, very good controls

Table 5: Summary of the effects of subsonic overflights on birds

INVESTIGATOR Study	Date	TYPE MAMMAL Domestic	Wild	TYPE SOUND Sonic (S)/ Subsonic (ss)	EFFECTS Negative	Neutral/Other	METHOD Field	Lab	IMPLICATIONS
Parker A/C noise Effects on Dairy Cattle	1960	Dairy cattle		(ss) noise within 3 mi. of 8 AF bases		No effects		Studied milk pro duction rates	Possible, but circumstantial
Ames Responses of Lambs to Noise	1969	Lambs (20)		(ss) 75-100dB		Some physiologic effects		Lab study	Possible, but no long term effects observed
Klein Reactions of Northern Mammal	1973		Caribou, bear, Moose, wolves	(ss) 81-103dB a/c noise	Caused some strong re-actions	Low flying a/c	Field observations		None, small sample size in some animals
Calef Reactions of Caribou to a/c	1976		Caribou	(ss) Helicopters & a/c below 300 ft	Panic & escape re-actions		Field observations		Possible
Borg Effects of Sound on Animal	1979	Rats		(ss) 80-85dB and 85+ dB	Hearing loss at 85+	No effects at lower levels		Lab study	Possible
Balabanov Guinea pig Reactions to Noise	1980	Guinea pigs		(ss) 15 Hz		Restless		Lab study	None, no correla-tions w/ a/c noise
Heudieser Effects of A/C on Pregnant Cow	1982	Pregnant cows (5)		(ss) 59 overflights	3 abortions			Lab study	None, small sample size

Table 7: Summary of the effects of subsonic overflights on mammals

INVESTIGATOR Study	Date	TYPE MAMMAL Domestic	TYPE MAMMAL Wild	TYPE SOUND Sonic (S)/ Subsonic (ss)	EFFECTS Negative	EFFECTS Neutral/Other	METHOD Field	METHOD Lab	IMPLICATIONS
Bond	1963	Swine		(S) 100-135dB, artificial		Heart rate up, No other effects		In pens	Direct
Casady Response of Farm Animals to Sonic Booms	1967	Horses, cattle, Sheep, dairy, turkey Chicken, & Pheasant		(S) 85-210 booms		Little effects, no productivity reduction	Ranches around base		Possible, incomplete data, habituation possible
Nixon Supersonic over flight Effects	1968	Cattle		(S) 50-118 psf, F-4C		Alert, running response, visual stimuli greatest	Observations on farms		Direct
Ames Physio Response of Lambs to Noise	1969	Lambs (20		(S) 75-100dB		Decrease heart rate, adrenal & pituitary gland decrease 20%		Lab study	Possible
Majeau-Chargois Sonic Boom Effects on Guinea Pigs	1969	Guinea pigs		(S) 130 dB, 1000, 1/sec	Hearing loss poss.	No long term effects noted		Lab study	Possible, but unrealistic study
Bouteiller	1970	Army dogs		(S) booms ?		Increased Heart rate, decreased attention	While dogs were in training		Possible, no data
Rylander SB Effects on Farm Animals	197[illegible]	Dairy, cattle (0), Sheep (18)		(S) 0.8-5.2psf, 42 in 4 days		Aggressive behav & some startle reactions		Lab study in Sweden	Possible, numbers small
Hubbard SB Effects on Deer	1972		Deer	(S) booms?		No effects	Field observations at Eglin AFB		None, no data
Travis SB Effects on Mink	197[illegible]	Mink		(S) 1.6-6.6 psf, real & simulated a/c sonic booms		No effects		Lab study	Direct, but habituation may have occurred
Sonic Boom Comm	197[illegible]	Pregnant sows (40)		(S) SST-type booms		No unusual behav or calving rate decrease		Lab study in Sweden	Possible, but no data available
Rylander Sonic Boom exposure Effects	197[illegible]	Reindeer [illegible]		(S) booms?		No effects		Corraled	Possible, controls were poor
[illegible] SB Effects of Lab Animals	197[illegible]	Mice [illegible]		(S) 2.2-4.5psf, [illegible], [illegible] intervals	Cochlea damage			Lab study	Direct, but unrealistic
[illegible] Effects of SB on Pinnipeds	[illegible]		Sea Lions, Seal Harbor Seals Elephant Seals	(S) 90dB		Some panic behav Mother pup sep. no harmful effts	Field observations		Possible, no controls

Table [illegible]. Summary of the effects of sonic booms on animals along side runways at Torrejon AB Spain and Lajes AB Azores Portugal leading us to believe that many species can adapt to aircraft noises. Can we correlate how we percieve these noises with how other animals percieve them? Probably not. In fact, that is one reason it's difficult to determine the effects of noise on animals- researchers try to determine effects by changes in behavior and physiology. Unfortunately, many of these changes were very subtle and so long-term that they have been overlooked.

Areas for Further Investigation

Shaw (1978) concludes that "of the many effects of noise on wildlife, interference with communication seems the most promising for further study at the present time." Cottereau (1972) stated that the "greatest research need is for critical observation of the response of aggregations of various social mammals and birds to sonic booms of measured overpressure and duration." This need is probably still true today except that we should be paying more attention to subsonic jet overflights where the aircraft are visible to the animals. Fletcher (1979) recognized the need for well controlled experiments concerning non-auditory effects of noise on animals. That need is still present today.

Newman and Beattie (1985) thought that a "significant amount of research has been conducted on the reactions of animals to noise," but that it has been "difficult to draw any general conclusions on the subject because there is much variability in response both between and within species." This fact coupled with the problem of some poorly designed studies, the difficulty with studying wildlife without influencing their behavior, and the number of variables involved have led us to the problem of inconclusiveness.

Further research suggested by Dufour's (1980) summary include investigation of long term noise exposures, verification of laboratory sensitivity studies to extrapolative application in wildlife studies, and ecological consequences of possible adverse physiological effects, masking and altered behavioral patterns.

In trying to specifically identify some of the technological gaps present, we have come to the following conclusions:

1. Sonic booms within the criteria of realistic Air Force operations (1-5 psf) do not appear to significantly affect animals. Since questions will continue to plague us concerning what happened in the Dry Tortugas with the Sooty Terns, we suggest a study in the Continental United States on the effects of sonic booms on a social, ground-nesting bird species. A variety of bird species would be applicable for this type of study (i.e. Snowy Plover, Mountain Plover, or Least Tern).

2. Sonic booms of moderate to high intensity (greater than 10 psf) may cause behavioral effects in many animals similar to natural environmental factors (i.e. thunder, earthquake, predator sounds, etc.).

Since the Air Force does not anticipate booms of this intensity, no research should be done in this area.

3. With the exception of Peregrine Falcons, no studies have dealt with endangered or threatened species. Since these species are specifically addressed in Environmental Impact Statements (EIS), we anticipate a need to study the effects of subsonic aircraft noise on some endangered or threatened species. Bald Eagles, Big Horn Sheep, and Pronghorns would probably be the best organisms for study considering the environment that the Air Force flies within and the types of animals best suited for study.

4. There is a definite lack of information concerning long term physiological effects of animals due to aircraft subsonic noise. For this reason, we suggest research in the areas of physiological stress and immunosuppression on animals due to aircraft noise.

5. Due to the many variables involved in the question of effects of aircraft flight noise on animals, we suggest studies on the effects of noise versus visual stimuli. These studies should include both domestic mammals and birds.

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